

# Cryo-Cooler Thermal Control System

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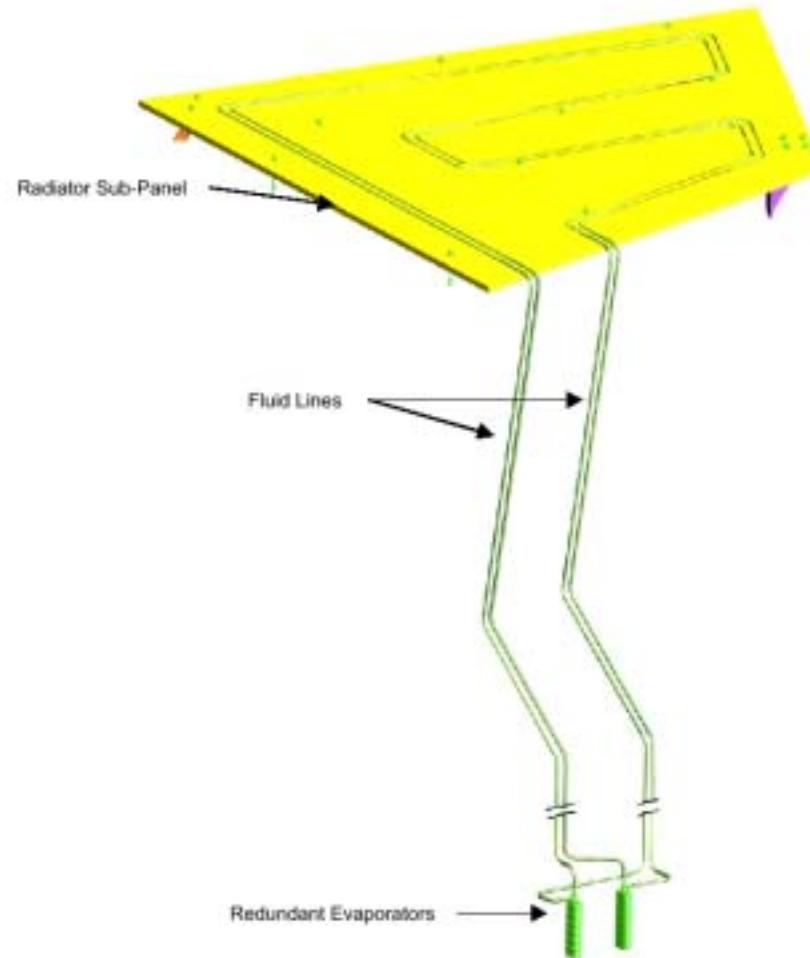
## 1. Introduction

- **AMS includes 4 Stirling Cryogenic Coolers (Cryo-Coolers), which extract parasitic heat from the thermal protection shields of the Helium cooled AMS magnet.**
- **Description of the performed thermal analysis for the AMS-02 loop heat pipes (LHP), which are implemented into the AMS Cryo-cooler thermal control system.**



## 2. Description of Cryo-cooler Thermal Control System

- AMS Cryo-cooler TCS consists of:
  - LHP evaporator,
  - pipelines and
  - condenser connected to the Zenith radiator panel.

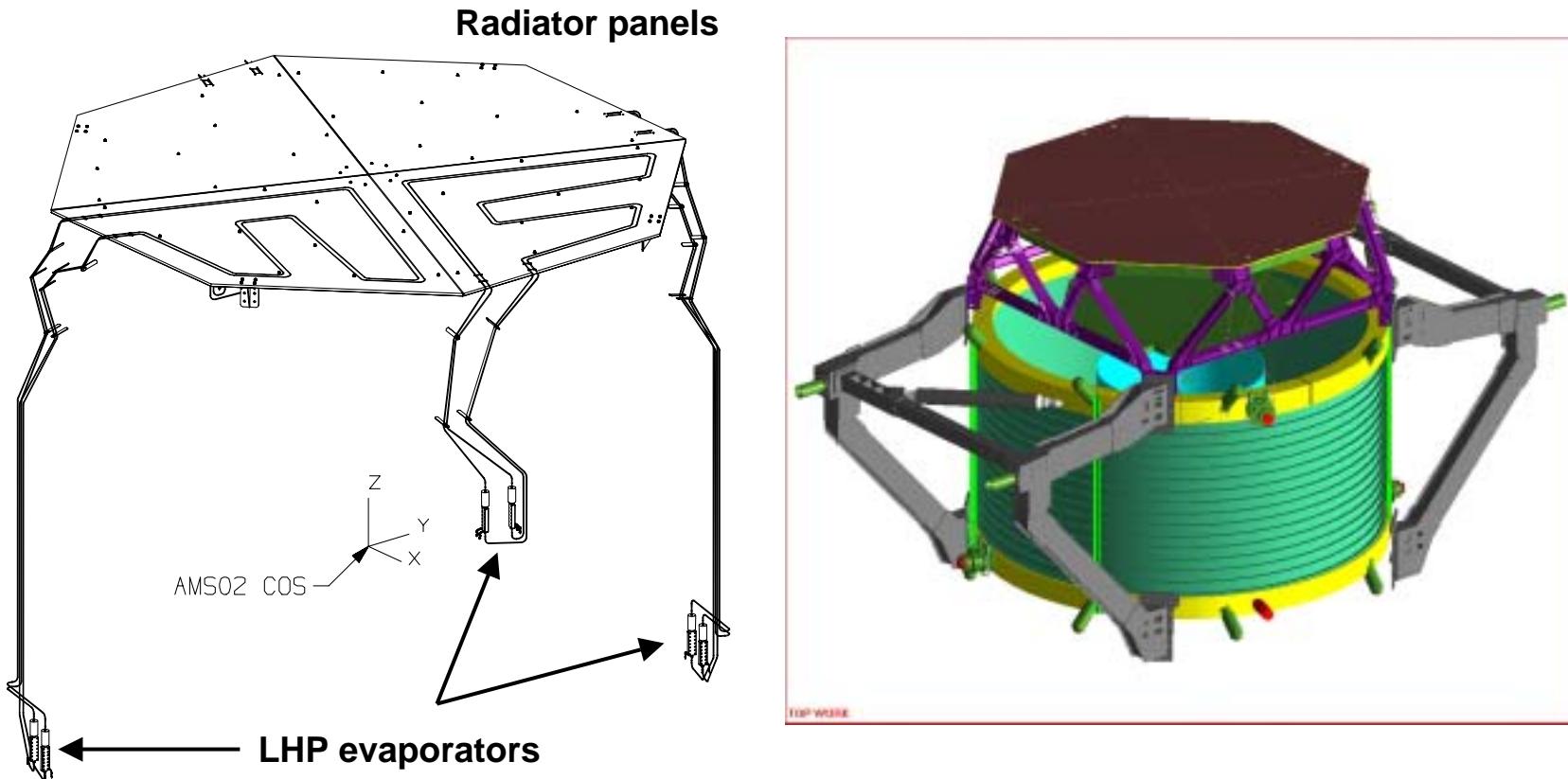


## 2. Description of Cryo-cooler Thermal Control System

- The LHP systems can be characterized as follows:
  - AMS contains four separate LHP systems
  - Each LHP system consists of:
    - two LHPs (for redundancy reasons)
    - one radiator sub-panel
  - The four radiator sub-panels have identical configurations including identical condenser lay out
  - The four LHP systems can be divided into:
    - Two identical LHP systems serving the two Cryo-Coolers at the lower Cryomagnet Assembly rim with longer fluid lines “Long LHP System”
    - Two identical LHP systems serving the two Cryo-Coolers at the upper Cryomagnet Assembly rim with shorter fluid lines “Short LHP System”
  - Except from the different fluid line length the Long and Short LHP Systems have different evaporator dimensions, especially different seizes of the compensation chamber. But all LHP Systems have identical mechanical interfaces to the Cryo-Cooler.

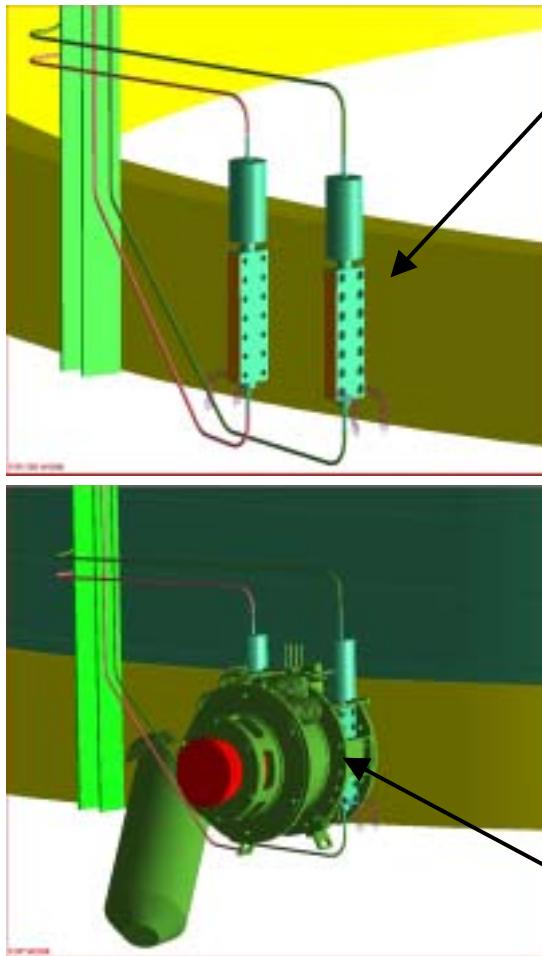
## 2. Description of Cryo-cooler Thermal Control System

- LHP systems (1/2):

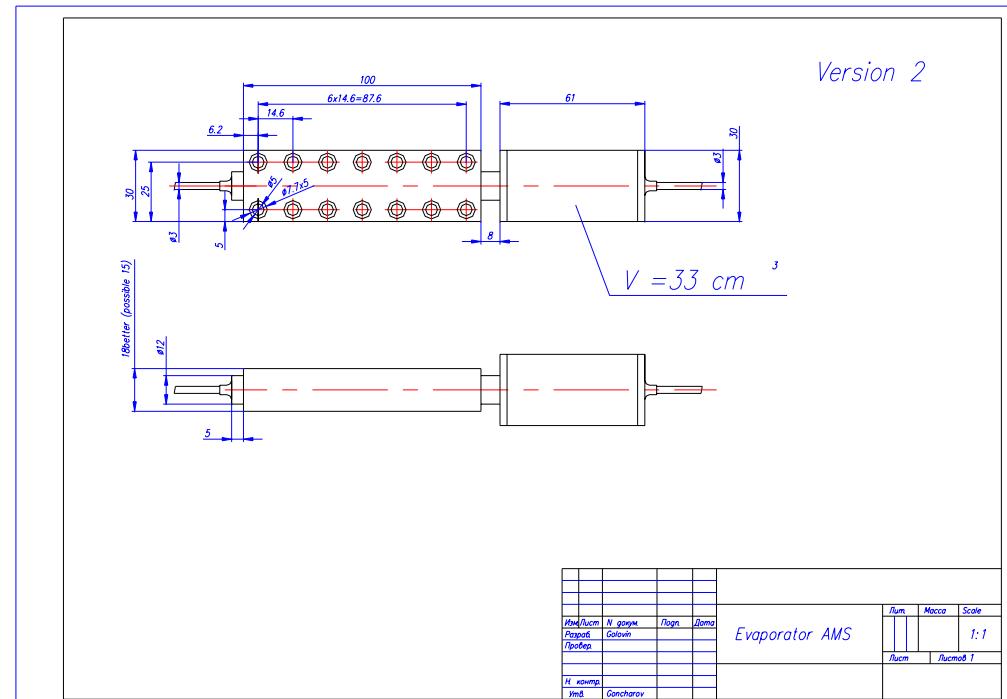


## 2. Description of Cryo-cooler Thermal Control System

- LHP systems (2/2):



LHP evaporator



Cryo-cooler

### 3. Main Features of LHP Thermal Mathematical Model (1/4)

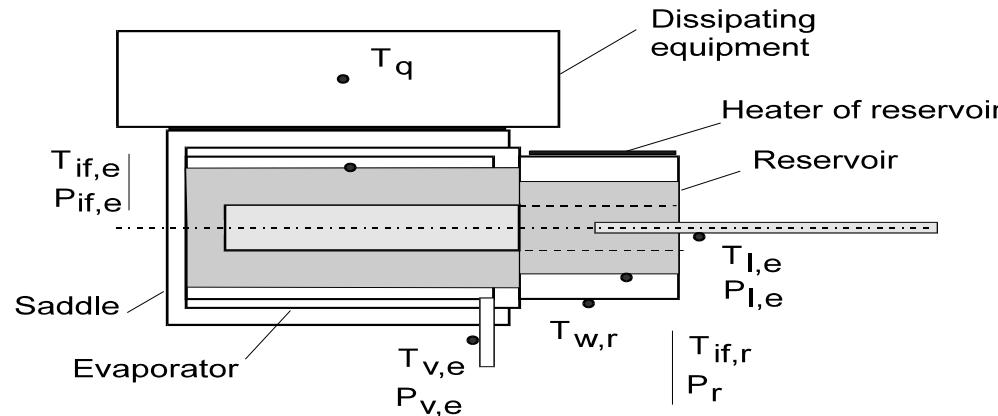
- The developed LHP TMM is able to simulate transient operational modes of entire loop under all spectrums of variations of environmental (i.e. under gravity and zero-g conditions) and heat load conditions, including start-up and switch-down. It has the following features.
  - The model nodes unite local conjugate energy, momentum and mass average balance over the node area.
  - Transient pressure, mass flow and momentum balance are calculated over entire loop
  - Conductive, flow enthalpy, radiative and convective links are calculated over the condenser-radiator
  - State of fluid is detected automatically by enthalpy balance at any location of entire loop: two-phase, pure saturated, sub-cooled liquid or super-heated vapour.
  - The condensation model is based on annular flow with variable thickness of condensate film under vapour-liquid interface stress balance.

### 3. Main Features of LHP Thermal Mathematical Model (2/4)

- Gravity term is included.
- Two evaporator models can be chosen independent from the availability of design parameters of evaporator and reservoir from LHP Developer. If no details are available, the appropriate uncertain parameters can be adjusted by results of ground test.
- The developed Interfacing Algorithm (IFA) allows LHP modeling at two levels:
  - low level (LLM, i.e. detailed LHP model) and
  - high level (HLM, few nodes representative of LLM at higher level).
- AMS LHP model at LLM consists of 5 nodes for evaporator zone, 176 nodes for condenser zone , 10 nodes for liquid pipeline and 10 nodes for vapour pipeline. The corresponding HLM model consists of 1 node for evaporator zone and 10 nodes for condenser zone.
- IFA executes necessary exchange between LLM and HLM to guarantee the adequate representation of LLM model at high level.

### 3. Main Features of LHP Thermal Mathematical Model (3/4)

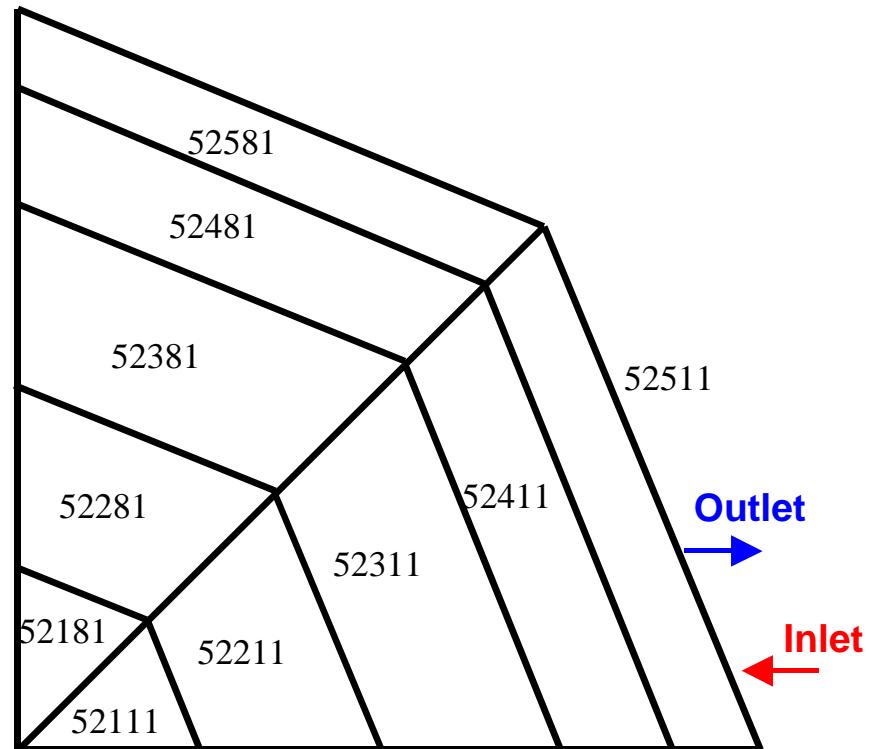
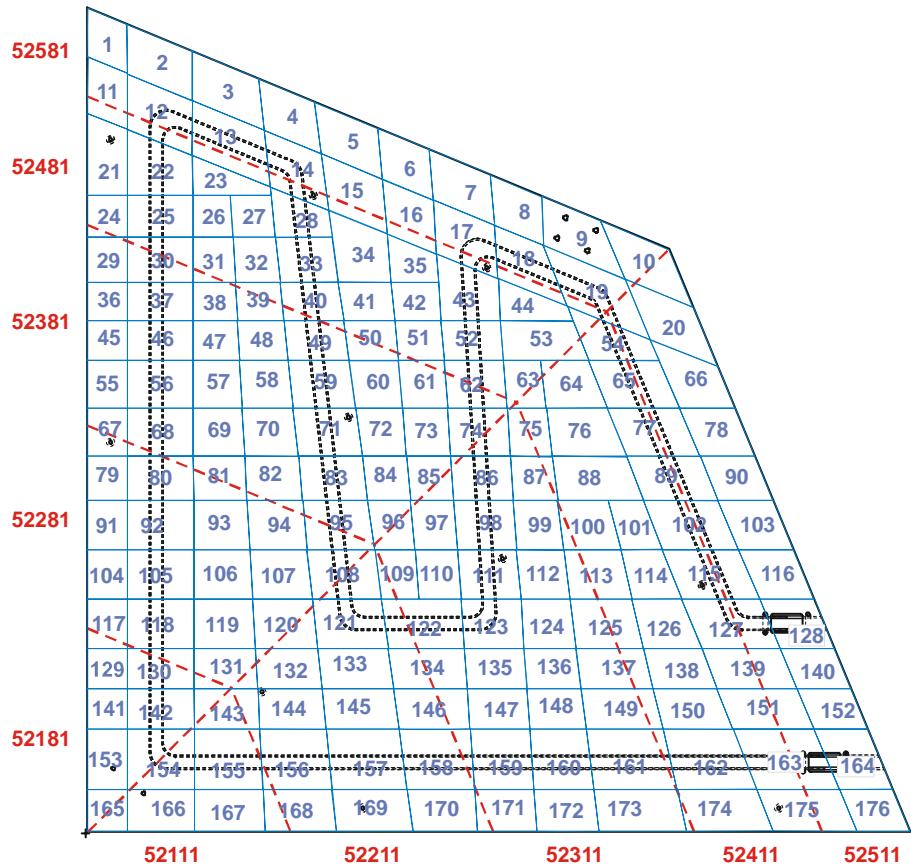
- Nodal layout of the evaporator at L-level :



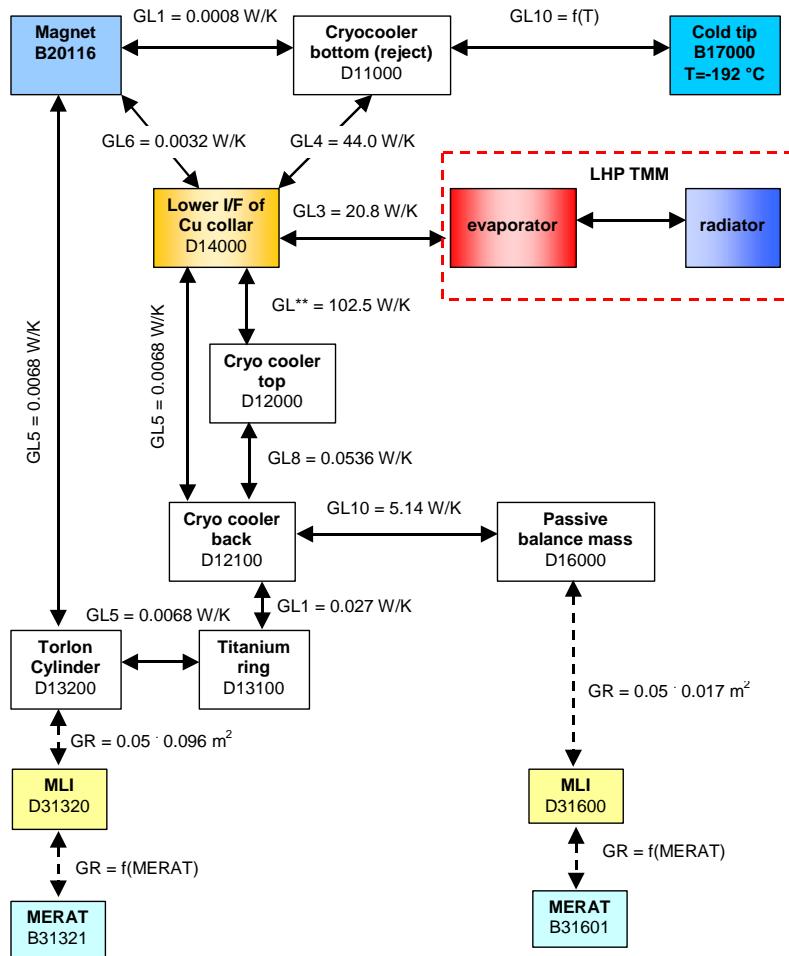
- These 5 nodes are presented by temperature:
  - $T_q$ : Temperature of dissipating element (i.e. here Cryo-cooler collar)
  - $T_{w,r}$ : Temperature of evaporator wall
  - $T_{if,e}$ : Temperature of vapour / liquid I/F in evaporator
  - $T_{w,r}$ : Temperature of reservoir wall
  - $T_{if,r}$ : Temperature of vapour / liquid I/F in reservoir
- The liquid inlet temperature  $T_{le}$  is the last node temperature of liquid pipeline.

### 3. Main Features of LHP Thermal Mathematical Model (4/4)

- L-I and H-I nodal layout of the enlarged AMS cryocooler radiator



## 4. Cryo-cooler Thermal Mathematical Model



### ● Temperature Requirements:

- Min. turn-on and operational temperature of the Cryo-cooler: -10 °C
- Max. operational temperature of the Cryo-cooler : +40 °C
- Min. non-operational and survival temperature of the Cryo-cooler: -40 °C
- Max. non-operational and survival temperature: +40 °C

### ● Dissipations:

- Minimum: 60 Watts / cryocooler
- Maximum: 150 Watts / cryocooler
- Nominal: 100 Watts / cryocooler

## 5. Thermal Analysis

- Environment Cases for the CRYO coolers and the Zenith Radiator:

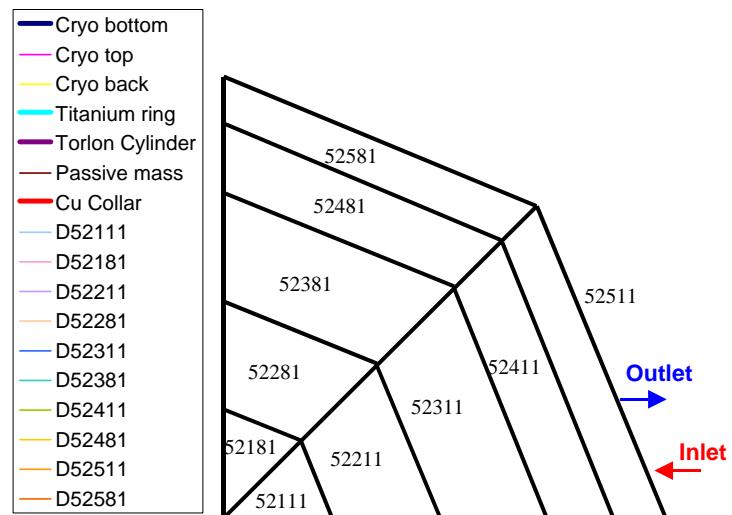
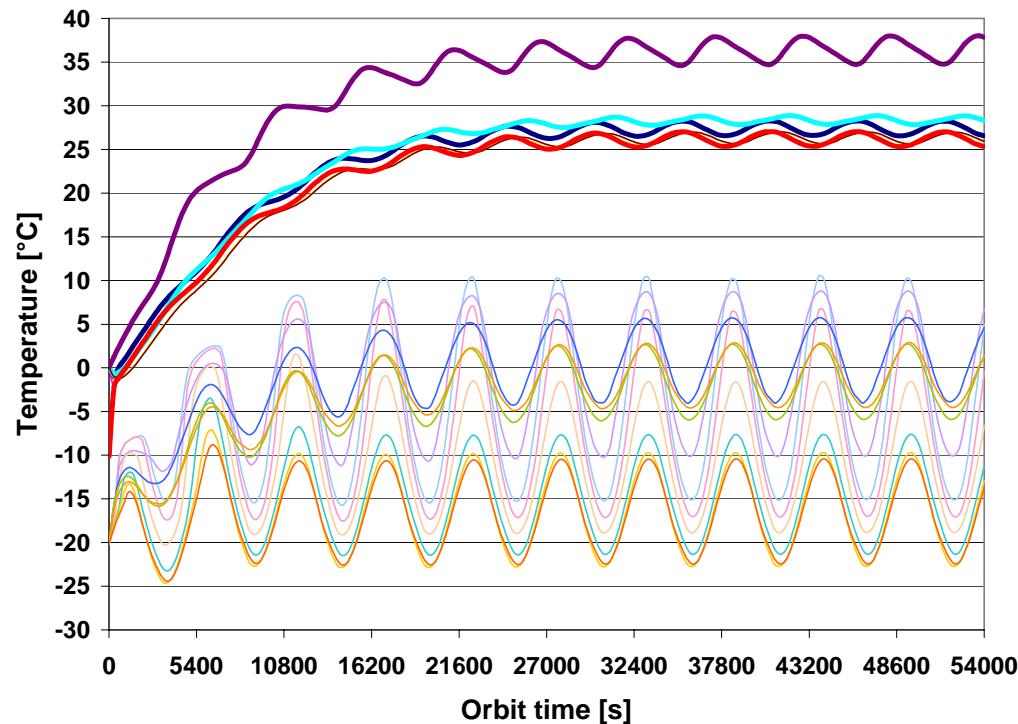
CGS input file:	CASE:	Meaning			
		$\beta$	Y	P	R
IF_DATA_B_75-15_15_15_COLD.xls	COLD	+75	-15	+15	+15
IF_DATA_B_75-15-20-15_HOT.xls	HOT	+75	-15	-20	-15
IFdata_B_0MPA.xls	NOMINAL	0	-2	-10	+1

- LHP and Radiator Material Properties and Main Dimensions:

Name	Dimensions	Material	$\rho$ [kg/m <sup>3</sup> ]	$c_p$ [J/kg K]	$\lambda$ [W/m K]
Face sheet out	$t = 1.6 \text{ mm}$	Al	2800	879	155
Face sheet in	$t = 0.3 \text{ mm}$	Al	2800	879	155
Radiator core	$t = 10 \text{ mm}$	ROHACELL	52	1500	0.028
LHP tubing	$I_{\text{Cond}} \approx 4.6 \text{ m}$ $I_{\text{long}} \approx 2.9 \text{ m}$ $I_{\text{short}} \approx 1.3 \text{ m}$	Al SS SS	2800 7900 7900	879 510 510	155 14 14
LHP evaporator	12 mm OD	SS	7900	510	14
LHP evaporator flange	100 x 30 x 15	Al	2800	879	155

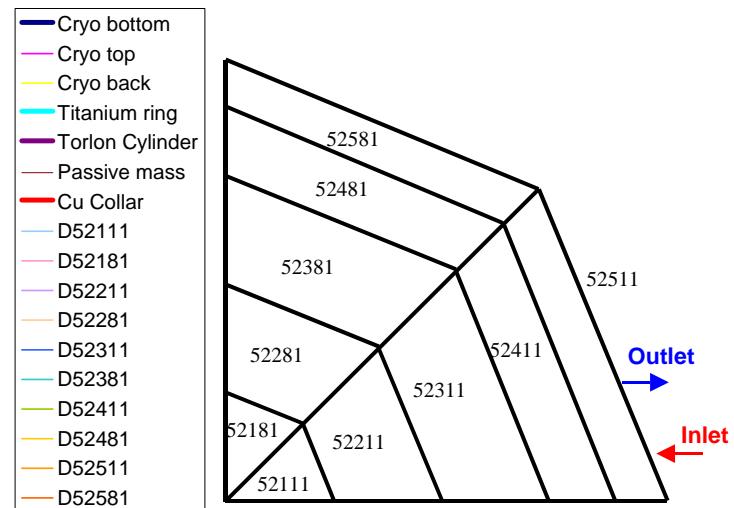
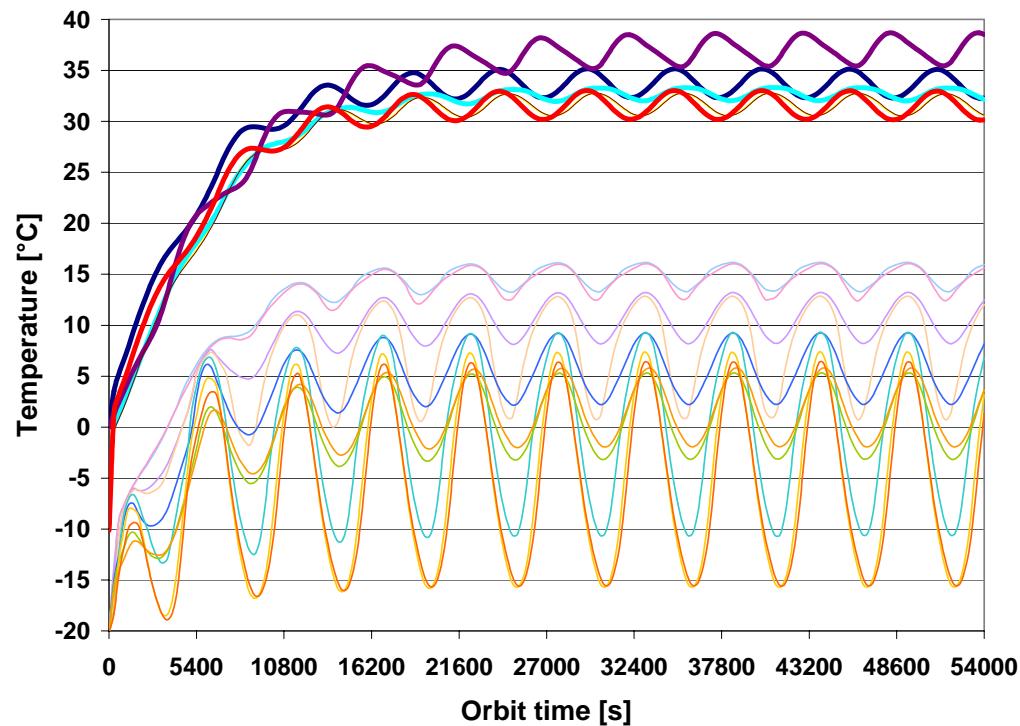
## 5. Thermal Analysis

- HOT CASE with 60 W:



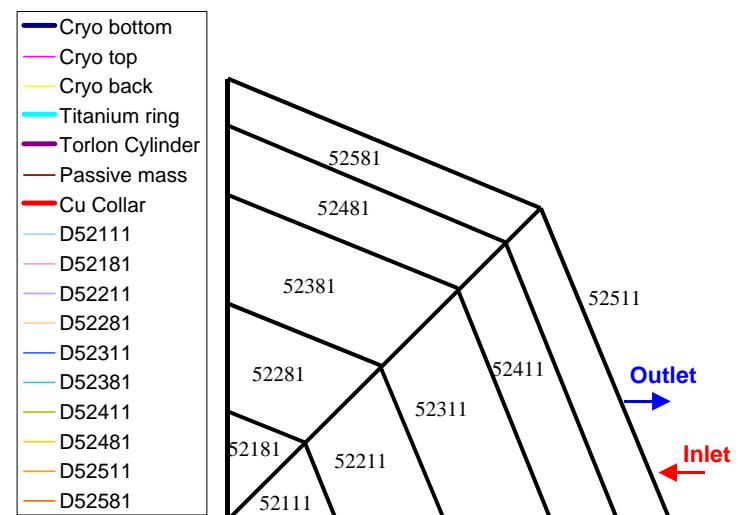
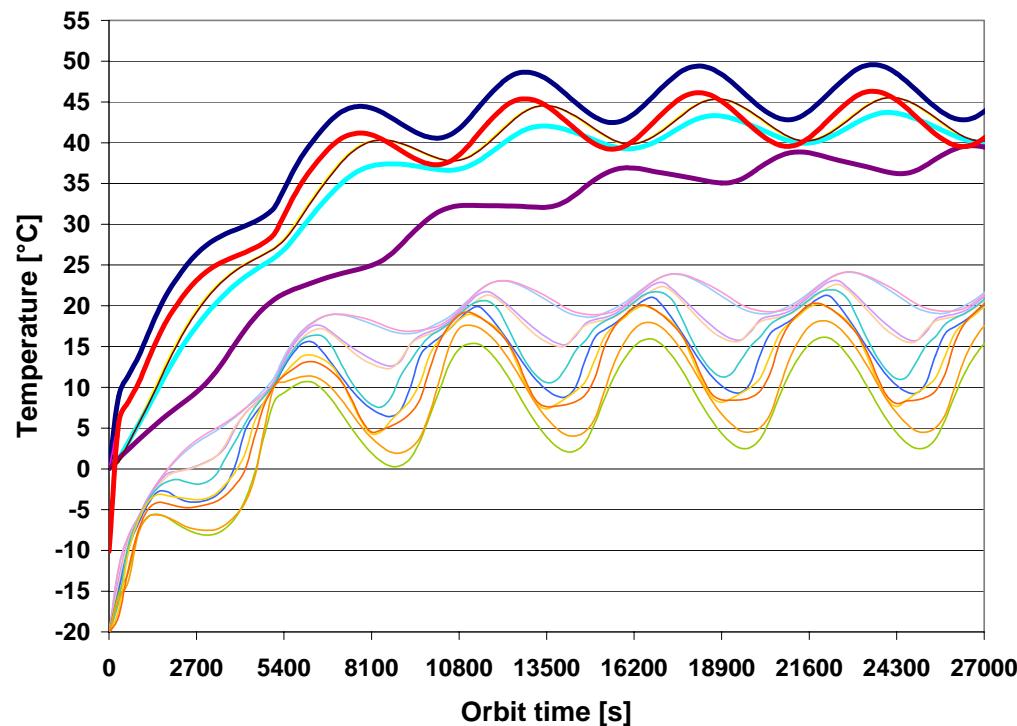
## 5. Thermal Analysis

- HOT CASE with 100 W:



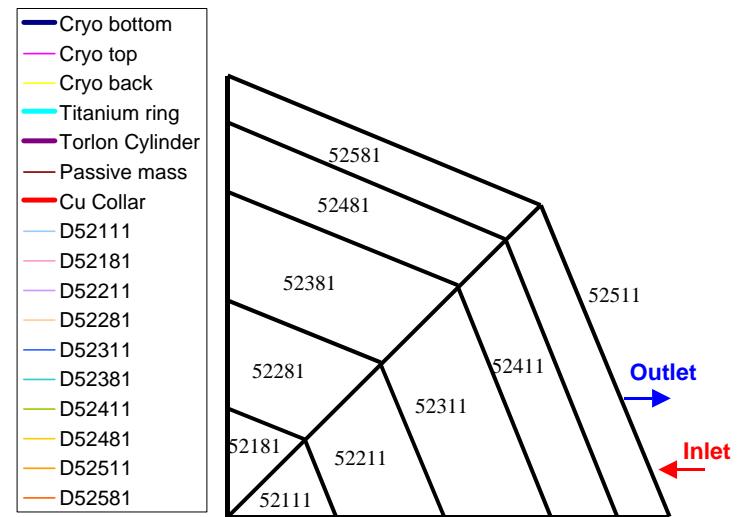
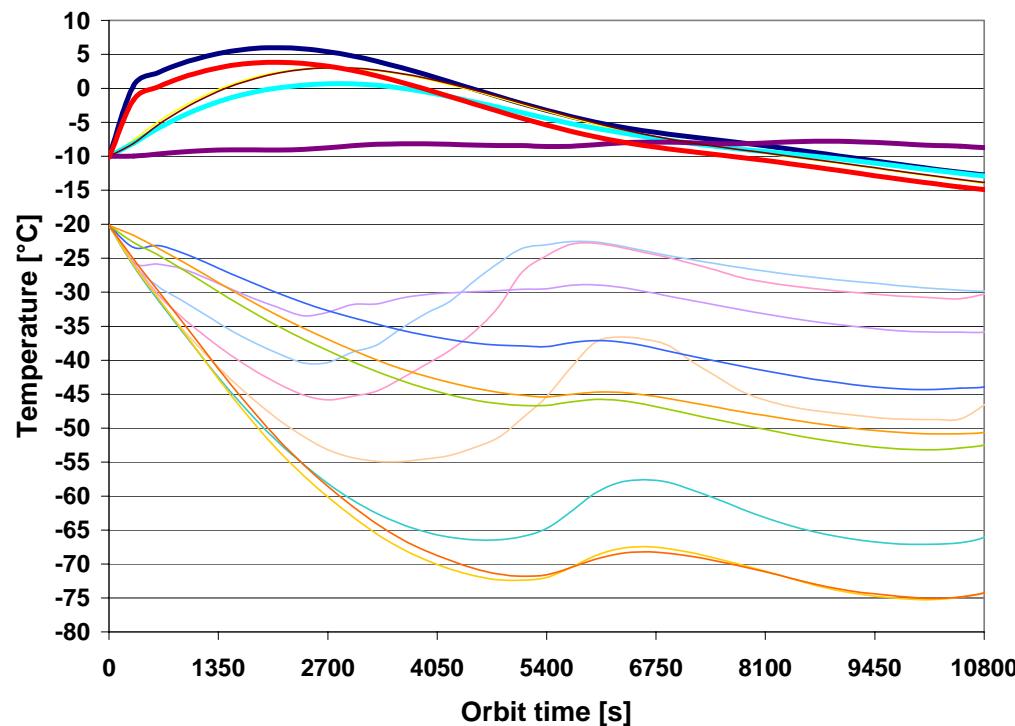
## 5. Thermal Analysis

- HOT CASE with 150 W:



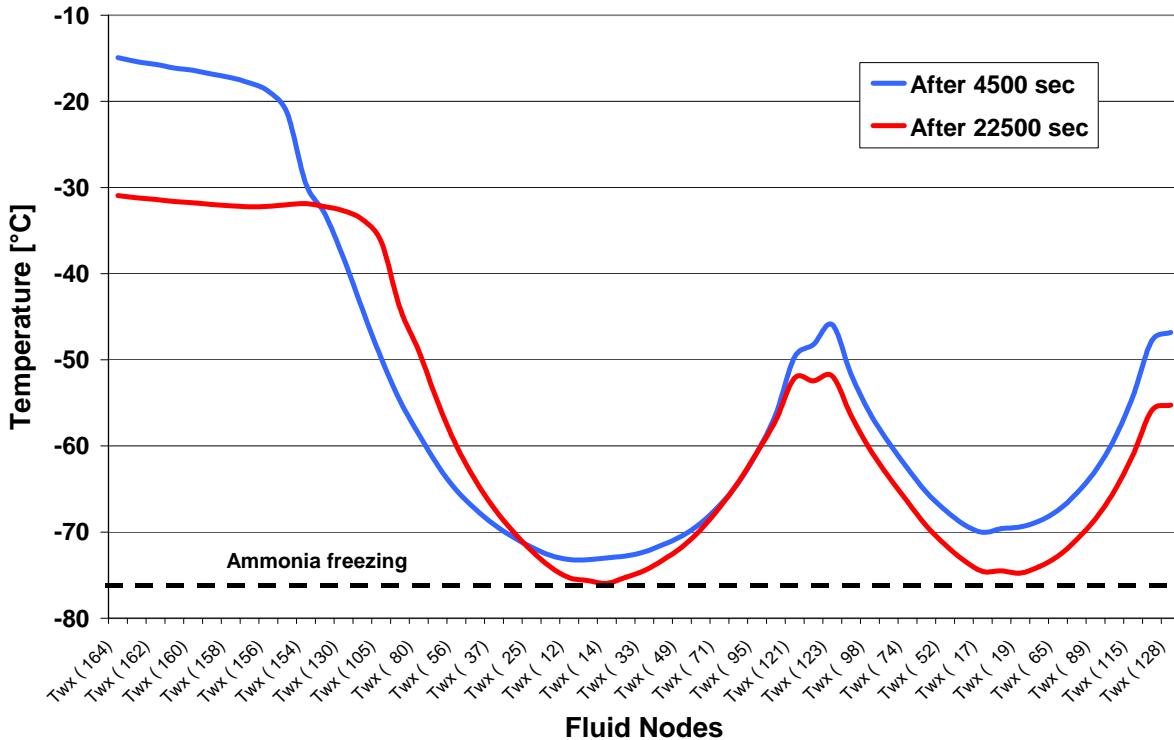
## 5. Thermal Analysis

- COLD CASE with 100 W:



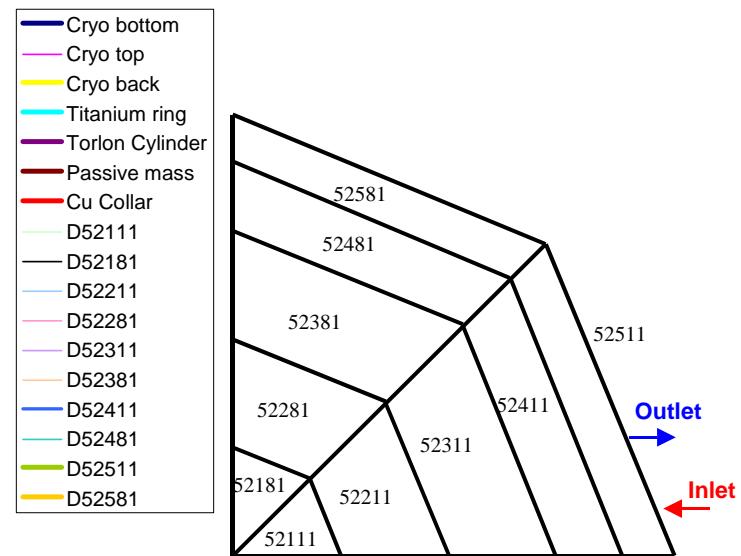
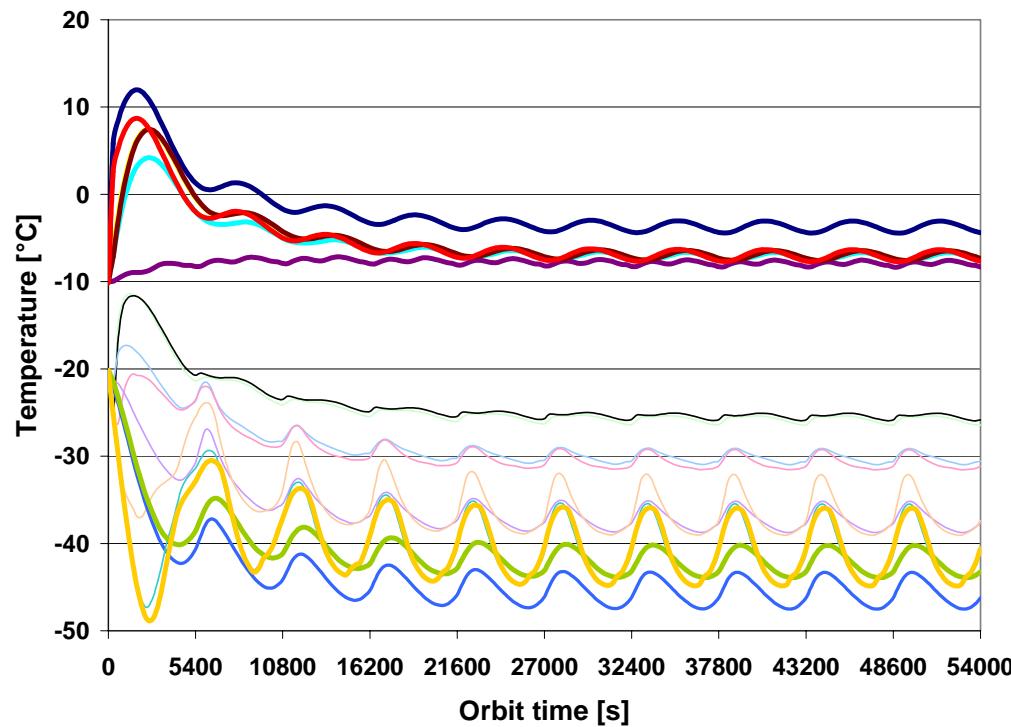
## 5. Thermal Analysis

- COLD CASE with 100 W:



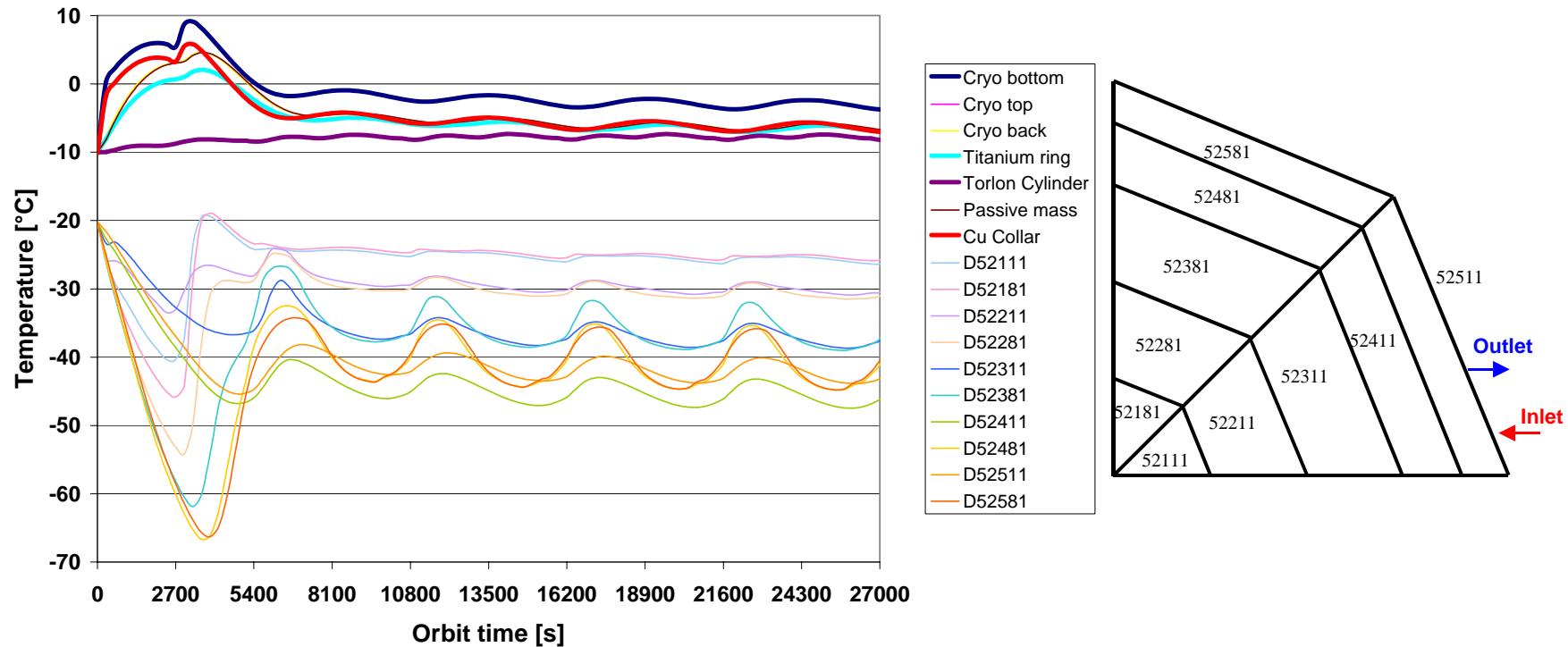
## 5. Thermal Analysis

- COLD CASE with 150 W:



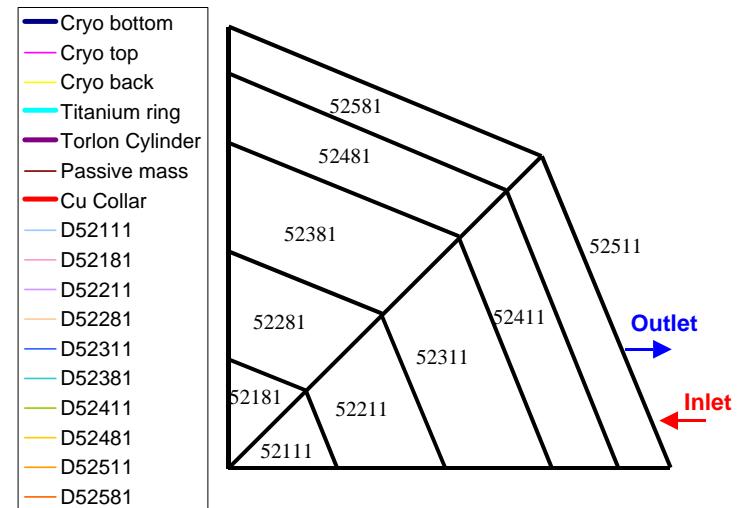
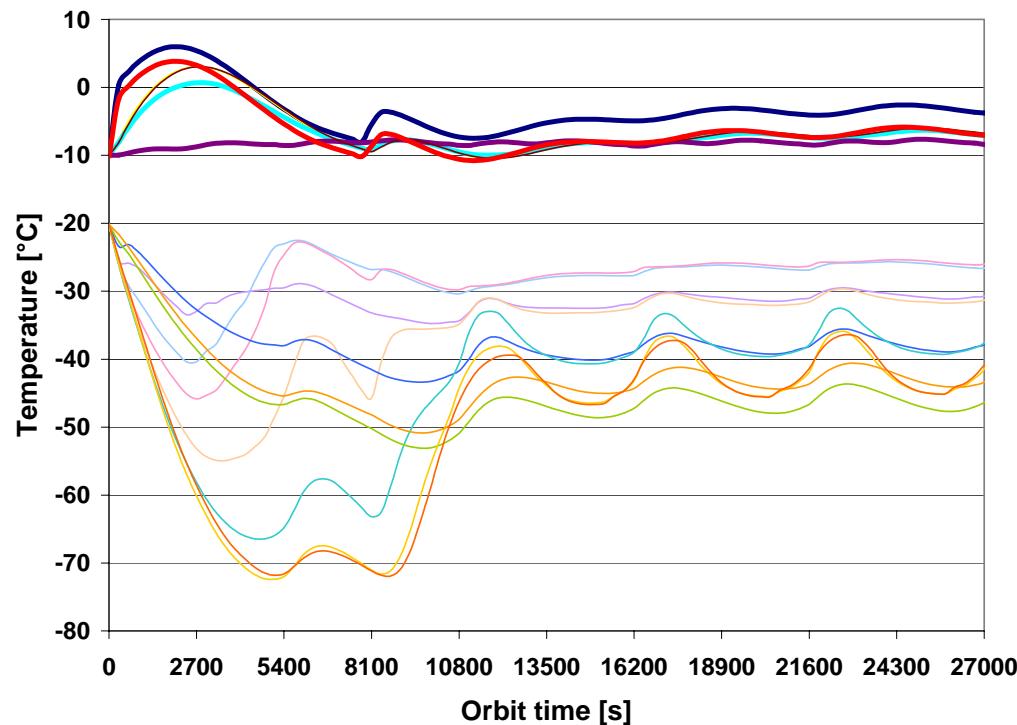
## 5. Thermal Analysis

- COLD CASE starting with 100 W and switching to 150 W, if Radiator Node D52581 is below  $-60^{\circ}\text{C}$**



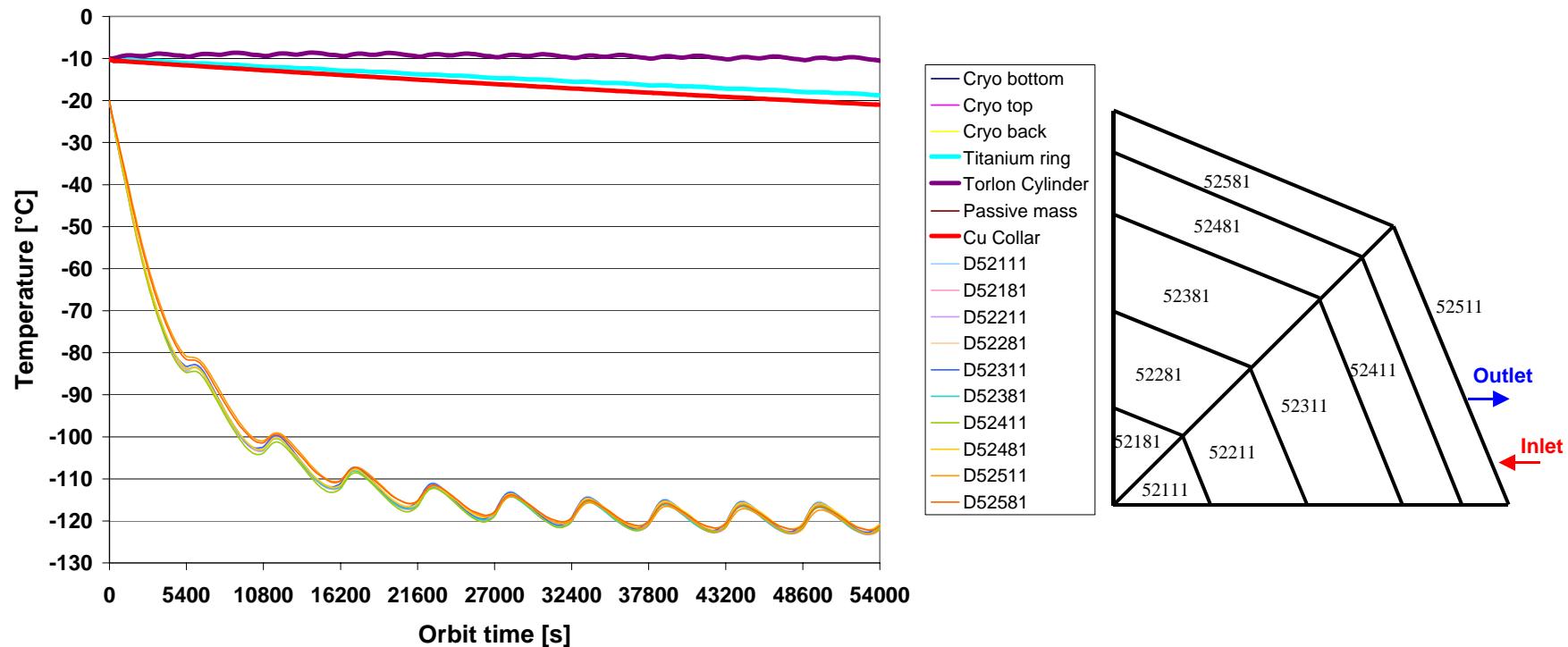
## 5. Thermal Analysis

- COLD CASE starting with 100 W and switching to 150 W, if Cu Collar is below  $-10^{\circ}\text{C}$



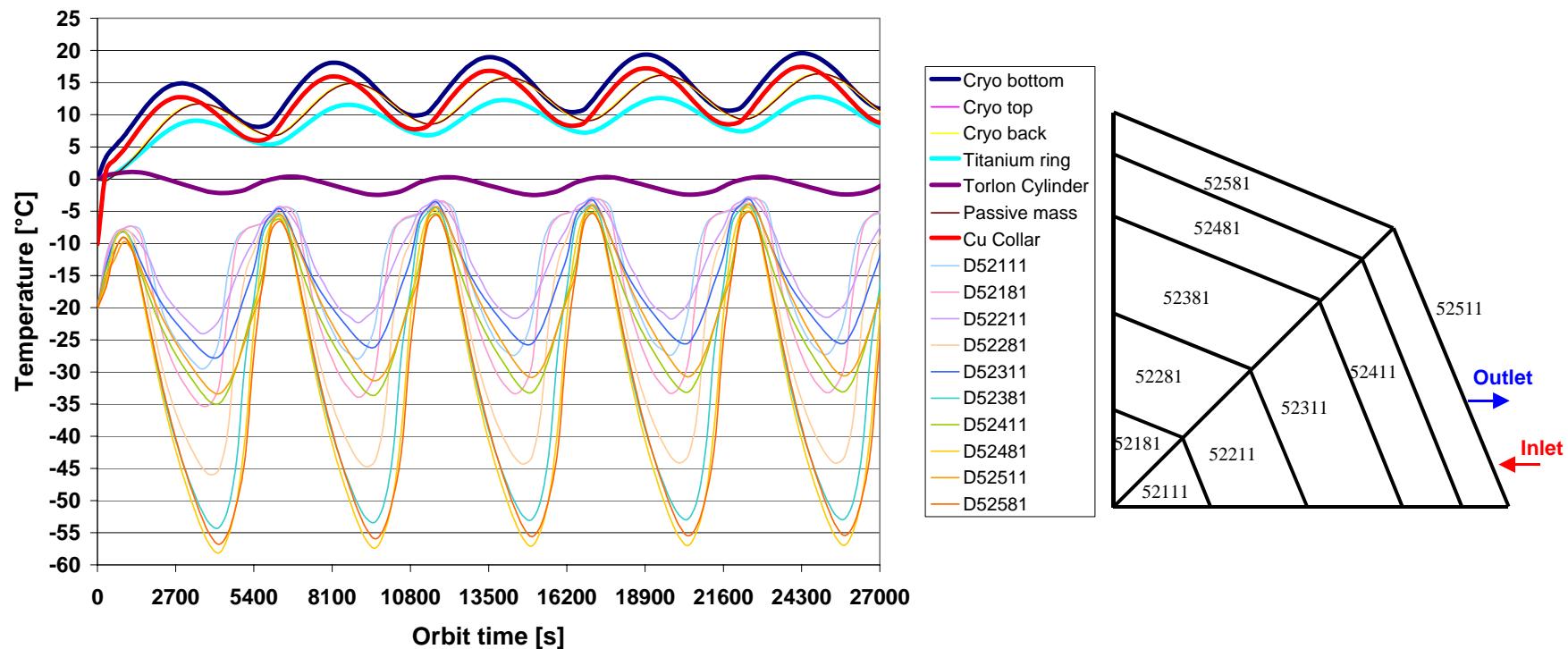
## 5. Thermal Analysis

- COLD CASE without Power:



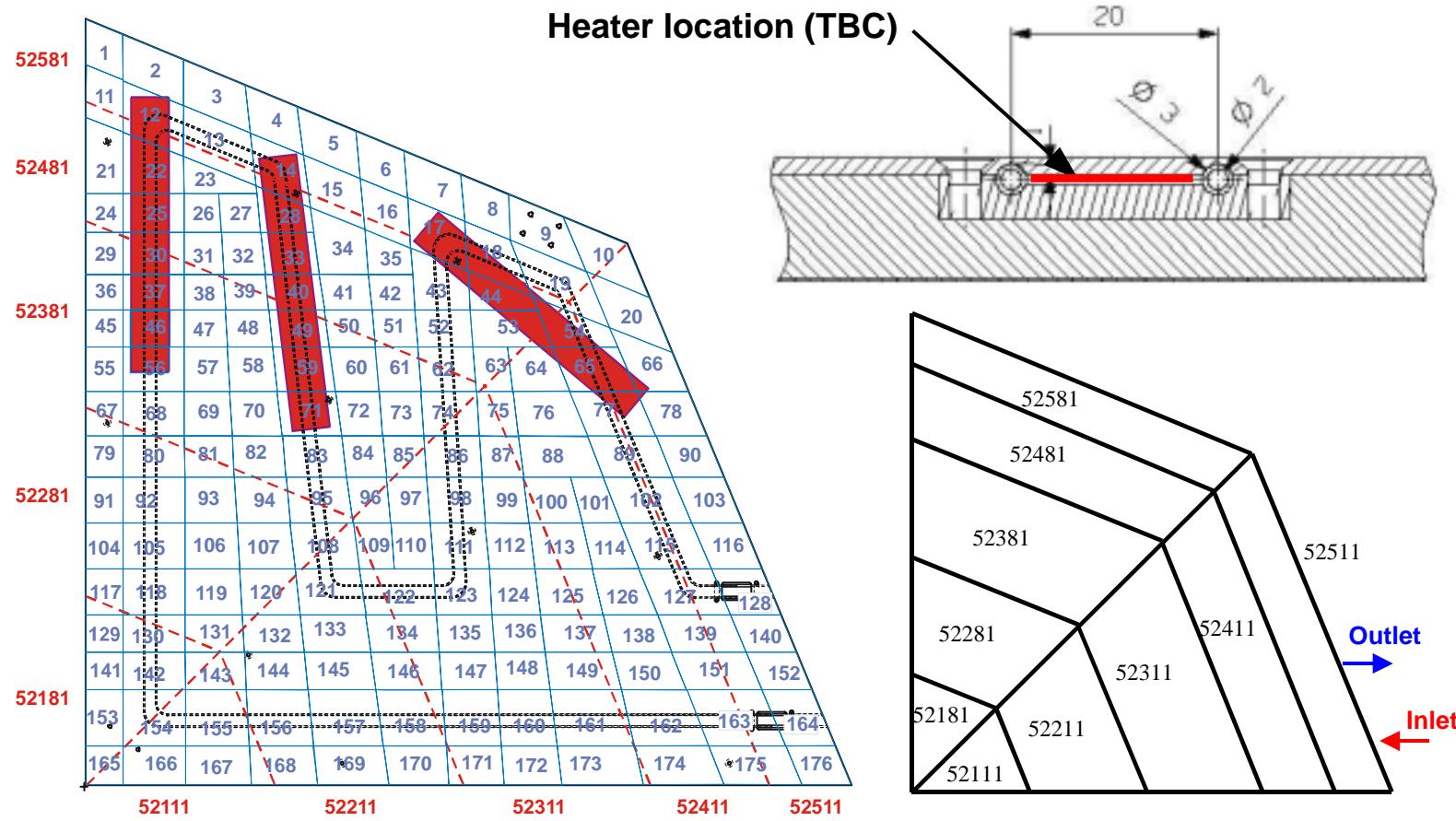
## 5. Thermal Analysis

- NOMINAL CASE for CRYO Cooler No. 4 with 100 W :



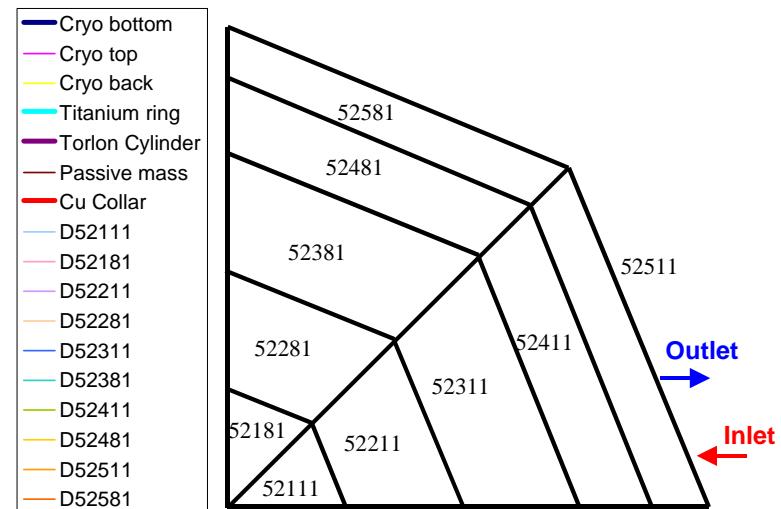
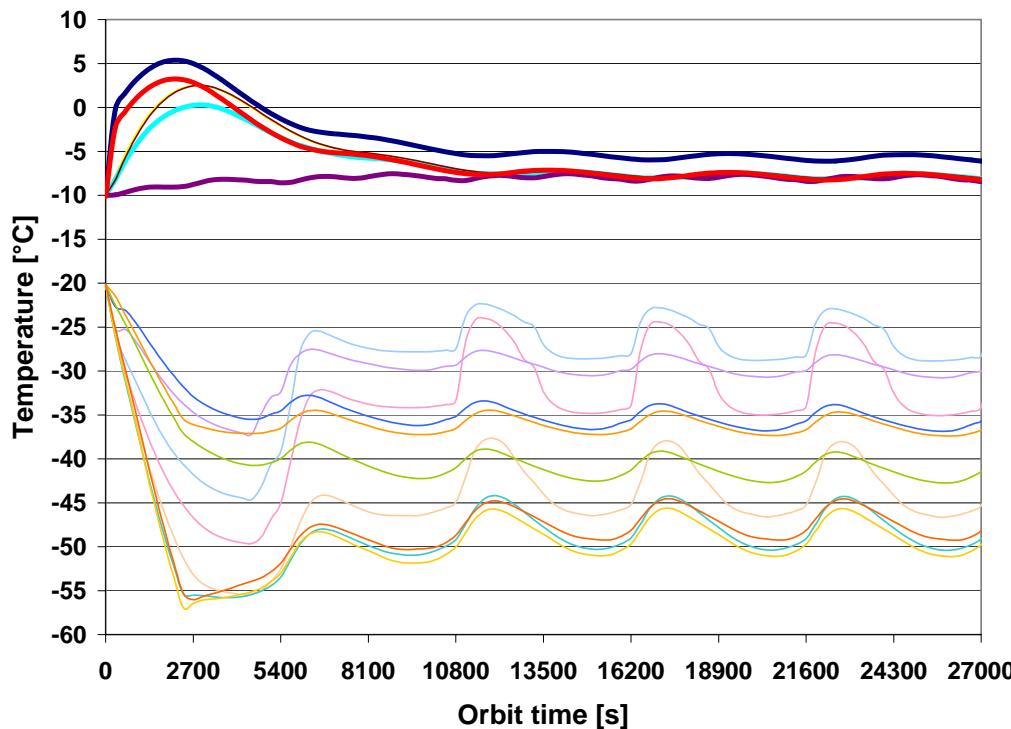
## 5. Thermal Analysis

- Substitution Heaters on the Zenith Radiator



## 5. Thermal Analysis

- Operating of the Cryo-Cooler with 100 W during COLD CASE plus Thermostat Regulated Substitution Heaters of 50 W located near the Fluid Lines:



## 6. Conclusions (1/2)

- The following analysis cases were performed for the AMS Cryo-cooler TCS:
  - Worst hot environment case with different power levels of the Cryo-coolers
  - Worst cold environment case with different power levels of the Cryo-coolers
  - “Typical” environment case with 100 W dissipation of the Cryo-coolers
  - Heater / power regulation during worst cold environment case to reach a radiator temperature above the freezing point of ammonia

## 6. Conclusions (2/2)

- The temperature requirements for the Cryo-cooler collar can be fulfilled for the defined worst hot and the “typical” environment cases with nominal (100 W) or minimum power (60 W) and with maximum power of 150 W during the worst cold case.
- The collar I/F temperature requirement for the worst cold case can not be reached with the nominal power of 100W due to the freezing of ammonia inside the fluid lines of the LHP system.
- To avoid the freezing of the ammonia additional power of about 50 W is necessary, which can be supplied due to additional dissipation of the Cryo-coolers (switch from 100 W to 150 W), or due to the substitution (start-up) heaters on the LHP evaporator flanges, or due to additional substitution heaters on the Zenith radiator (located between the fluid lines).
- The substitution heaters ( $P = \text{TBD}$ ) on the radiator are also needed to warm-up the radiator after AMS-02 power off conditions.